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Veröffentlichungsversion / Published Version
Arbeitspapier / working paper

Zur Verfügung gestellt in Kooperation mit / provided in cooperation with:
Wissenschaftszentrum Berlin für Sozialforschung (WZB)

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Working Paper

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WZB Discussion Paper, No. SP III 2018-303

Provided in Cooperation with:
WZB Berlin Social Science Center

Suggested Citation: Butollo, Florian; Jürgens, Ulrich; Krzywdzinski, Martin (2018) : From lean production to Industrie 4.0. More autonomy for employees?, WZB Discussion Paper, No. SP III 2018-303, Wissenschaftszentrum Berlin für Sozialforschung (WZB), Berlin

This Version is available at:
http://hdl.handle.net/10419/183606

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Berlin Social Science Center

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Discussion Paper

SP III 2018–303

October 2018

WZB Berlin Social Science Center

Research Area
Digitalization and Societal Transformation

Project Group
Globalization, Work, and Production

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Abstract

The article examines the relationship between lean production and *Industrie 4.0* focusing on the question of autonomy in the work process. In contrast to the claim made by official *Industrie 4.0* concepts that the autonomy of the employees would increase, we see in the current implementation projects a tendency towards greater standardization and control of work. This is in continuity with concepts of lean production, but neglects the participation-oriented elements of lean production such as teamwork and shop-floor-based improvement activities. Our argument is developed by analyzing practical examples from three relevant fields (digital assistance systems, data-based process management, modular assembly). The conclusions of this article also discuss the extent to which the concept of individual autonomy is suitable for the assessment of *Industrie 4.0* concepts, given the high levels of interdependence already achieved in production processes.

Key words: Technological change, production systems, work organization, labor relations, manufacturing

JEL classification: J24, M54, O33

Von Lean Production zur Industrie 4.0. Mehr Autonomie für die Beschäftigten?

Zusammenfassung

Der Beitrag untersucht das Verhältnis von Lean Production und Industrie 4.0 in Bezug auf die Frage der Autonomie im Arbeitsprozess. Im Unterschied zu der häufig in der Diskussion über Industrie 4.0 vorgebrachten Behauptung, dass sich die Dispositionsspielräume der Beschäftigten vergrößern würden, sehen wir in den bisherigen Umsetzungskonzeptionen eine Tendenz zur stärkeren Standardisierung und Fremdsteuerung von Arbeit. Dies steht durchaus in Kontinuität zu Konzepten der Lean Production, wohingegen die in den letzteren enthaltenen beteiligungsorientierten Elemente einer stärkeren Einbindung des Shopfloors in Entscheidungs- und Verbesserungsprozesse in Industrie-4.0-Ansätzen geringe Aufmerksamkeit erhalten. Dieses Argument wird anhand der Analyse von Praxisbeispielen aus drei relevanten Feldern (digitale Assistenzsysteme, datenbasiertes Prozessmanagement, modulare Montage) entwickelt. In den Schlussfolgerungen wird darüber hinaus auf die Frage eingegangen, inwieweit das Konzept der Autonomie angesichts der bereits heute erreichten Interdependenz in Produktionsprozessen als Kriterium für die Bewertung von Industrie-4.0-Konzepten geeignet ist bzw. weiterentwickelt werden sollte.

Schlüsselwörter: Technologischer Wandel, Produktionssysteme, Arbeitsorganisation, Arbeitsbeziehungen, Verarbeitendes Gewerbe

JEL Klassifikation: J24, M54, O33

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1. Introduction[1]

Accounts of *Industrie 4.0* often refer to the new technologies' potential to improve working conditions. In addition to ergonomic improvements, particular emphasis is placed on aspects of autonomy. The "Implementation Recommendations" of Acatech and Forschungsunion (2013), one of the founding documents of *Industrie 4.0*, are one such example (cf. also Reinhart et al. 2017, p. 63):

> "It is highly likely that work in *Industrie 4.0* will place significantly higher demands on all employees in terms of complexity, abstraction, and problem solving. In addition, employees will be required to have very high levels of self-direction, communicative skills, and self-organization abilities. In short: Employees' subjective skills and potential will face even greater challenges. This offers opportunities for qualitative enrichment, interesting work contexts, increasing individual responsibility, and self-development."
> (Acatech/Forschungsunion 2013, p. 57)

However, the question arises as to whether these technological promises are justified, especially since initial research findings contradict these expectations of improved work quality and increasing autonomy, instead finding that, since the introduction of *Industrie 4.0* concepts, structurally conservative developments are dominating (see Hirsch-Kreinsen 2018) and innovative approaches to work organization are still lacking.

In the following, we seek to discuss the issue of autonomy of work in an *Industrie 4.0* environment by systematically questioning this concept with respect to continuities and discontinuities with the lean production system, which is still dominant in Germany and globally. We therefore do not take the technical possibilities themselves as our point of departure and derive the (possible) effects on work from them, but concentrate on the use of technology in existing production systems and the changes—technology-related and otherwise—in them. In our view, this approach is in line with the prevailing incremental way in which the new digital technologies have been introduced. Instead of assuming that the emergence of new technologies automatically leads to new stage of industrial production, we see *Industrie 4.0* as a *bundle of technologies* that are integrated selectively into existing production systems depending on the respective contexts, i.e. the sector, products and processes affected. Significant changes in process and work organization that affect the extent of worker autonomy may emerge as a result of these technologies. However, the changes should be interpreted with regard to their path dependencies on previous practices.

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[1] The German version of the paper was published as: Florian Butollo, Ulrich Jürgens, Martin Krzywdzinski 2018: Von Lean Production zur Industrie 4.0. Mehr Autonomie für die Beschäftigten?, Arbeits- und Industriesoziologische Studien 11(2): 75-90.

In the following, we first summarize the discussion on process organization and the autonomy of work within the context of lean production (Section 2). We then go on to discuss three technology-related developments that we regard as significant innovations (Section 3): the use of digital assistance systems, new control systems in automated manufacturing areas and maintenance, and (currently still experimental) new concepts of modular assembly. The empirical findings call into question the technological promise of greater autonomy in work processes. The use of digital technology can be clearly located within a continuous trend towards the greater standardization of workflows. Yet the complementary element of an integration of the shop floor into improvement processes, which was at least conceptually a cornerstone of work organization in lean production, has hardly been taken into account in recent *Industrie 4.0* approaches. In an examination of prospects for the future (Section 4), we reflect on this finding with reference to Adler's theses (2007), which criticize the sociology of work debate's fixation on the concept of autonomy. We also raise the question of whether, in addition to autonomy and participation, other criteria should also be taken into account when assessing *Industrie 4.0* concepts, for example, the potential of these concepts to aid the integration of new groups of employees or help meet changing needs with regard to working hours and flexibility.

2. Standardization and participation in lean production

Since at least the 1990s, lean production has been the internationally dominant reference model for designing industrial production systems. Lean production was systematically developed and implemented over a long period, from the mid-1940s to the 1970s at Toyota (Fujimoto 1999; Holweg 2007; Shimokawa/Fujimoto 2009; Jürgens 2017).

The original core of this system is the just-in-time principle (Krafcik 1988, p. 43), which is essentially just another way of describing the flow principle, which Henry Ford brought to prominence with his production system for the Model T (Williams et al. 1992). Yet just-in-time is only seemingly a simple system, and the more complex the process chains become and the more organizationally differentiated they are, the more difficult the system is to implement. It requires producing the precise quantity of each elementary component needed for the next manufacturing step at every point in the value chain. This in turn implies a high degree of interdependence between all actors and processes and makes precise timing and matter-of-fact coordination necessary. In this respect, lean production is an extremely interdependent, failure-prone, and "nervous" system (Krafcik 1988).

Part of lean production's self-image and recipe for success is that robust organizational routines are necessary to cope with this extreme interdependence: flat hierarchies, the immediate rectification of errors, a strengthening of local problem-solving competences, and above all the so-called Kanban system, by means of which the supply of materials is regulated according to needs (cf. on the significance of the Kanban system Shimokawa/ Fujimoto 2009, p. 16).

The just-in-time principle has also resulted in both restraint and caution with regard to automation measures, as these—according to the assumption—almost inevitably lead to waste in the form of overproduction and thus interim storage in the production process due to fluctuating demand and the need to fully utilize existing facilities for cost reasons. Nevertheless, digital technologies were quickly implemented in lean production systems, in particular enterprise resource planning (ERP) and manufacturing execution systems (MES) (cf. Mormann 2016; Pfeiffer 2003).

The characteristics of lean production have had mixed consequences for work on the shop floor. Lean production requires a strict adherence to prescribed operation standards and is thus in the tradition of Taylorism (cf. Dohse et al. 1984). Only a strict adherence to standards can enable a synchronization of the various processes. Standardized work is also a prerequisite for the optimization of work processes and troubleshooting. Only in standardized processes can the causes of errors be identified, which is why optimized solutions must always be set as new standards (Liker/Hoseus 2008; Springer 1999).

Yet the system's high interdependence and sensitivity to disruptions requires ongoing optimization and problem-solving processes involving the knowledge and experience of all shop floor actors. Participation in continuous improvement activities is thus a functional requirement and not a concession to labor (Jürgens/Krzywdzinski 2016; Liker/Hoseus 2008). Here, lean production goes beyond classical Taylorism and tempers the separation of planning and execution that is characteristic for the latter. Adler (2007) has emphasized this point in order to question the fixation of criticism of lean production on the concept of autonomy. He has argued that in view of the high interdependence of actors in value chains in modern industry, individual autonomy in the work process is hardly feasible. The more relevant criterion for assessing the quality of work is thus the extent to which employees can participate, including questions of control and governance of the entire company.

Now, it should be noted that the reality of lean production systems—even in Japan and Toyota—only partially reflects the model. In particular, the opportunities for employees to participate are often limited (Fucini/Fucini 1990; Graham 1995; Ihara 2007; Stewart et al. 2009; Jürgens/Krzywdzinski 2016). In many companies, continuous improvement processes (CIP) are rituallistically ossified and little attention is paid to the contribution of workers. Nevertheless, the tension between the standardization of work and the participation of employees in standard setting remains a crucial point in the design of work within lean production. To what extent is this balance changing with the evolution of production systems due to the use of *Industrie 4.0* technologies?

3. *Industrie 4.0* and autonomy: Continuity or breach with lean production?

Whether it is labelled a "revolution" or not, the distinctive feature of *Industrie 4.0* is above all the introduction and diffusion of the internet of things, which promotes the networking of assembly parts, transport carriers, machines, and measurement instruments. This enables new forms of digital process analysis, control, and optimization based on real-time information exchange, big data, and machine learning, along with the use of assistance systems that provide information in the work process in a situation-specific and real-time manner (Kagermann 2014).

As already mentioned, these technologies are used selectively and incrementally, with a number of factors playing a role—from the actors' perception and framing of changes, to the resources and objectives of the companies in question to the forms of process and work organization practiced in each case, which accordingly offer different starting points for digitally mediated optimization (cf. Hirsch-Kreinsen 2018). Hence, *Industrie 4.0* is rather to be conceived as a bundle of technologies with context-specific applications than as a comprehensive new stage of production.

This perception is echoed by academic contributions from the engineering sciences that emphasize that there is no rupture between lean production and *Industrie 4.0*, thus contradicting the revolutionary metaphor widely invoked in the media. In fact, most articles emphasize the compatibility of both approaches, and lean production is even seen as a prerequisite for the successful introduction of *Industrie 4.0* (cf. Dombrowski et al. 2017, Schlick et al. 2014; Rüttimann/Stöckli 2016; Meier 2017; Buer et al. 2018). In their comparison of lean production and *Industrie 4.0*, Schlick et al. (2014, p. 76) state "that neither the goal of optimization nor the areas to be optimized will change in the context of *Industrie 4.0*." Rüttimann and Stöckli (2016, p. 499) recommend that production managers implement lean production instead of waiting for the "promised land" of *Industrie 4.0*. The latter, they state, is "the topping on that cake. It makes Lean Production more flexible; whether it makes it faster, smoother, and more stable and more accurate has to be proven" (ibid., p. 500).

However, the relationship between lean production and *Industrie 4.0* can also be defined differently as it pertains to work. In this vein, the representatives of *Industrie 4.0* promise that data-based analysis and optimization are the key to managing increasing demands regarding quality, time-to-market, and interdependencies in the supply chains. Here, a shift appears to be occurring away from lean production's emphasis on shop-floor-based experiential knowledge, which is taking a back seat to data-based optimization. At the same time, the expansion of digital knowledge management and assistance systems is expected to support the integration of different groups of employees and especially of semiskilled workers into the work processes by way of instant instruction on standardized working routines on the job. In the following, we will discuss these points based on three application areas in which *Industrie 4.0* technologies are used: the application of digital assistance systems in logistics and assembly, data-optimized control and assistance in the area of automated equipment operators and maintenance work, and changes in assembly line work as part of new modular production concepts.

3.1 The use of assistance systems in logistics and assembly

Digital assistance systems are a central element of the *Industrie 4.0* technology bundle. In the following, we will discuss their use in the areas of logistics and assembly work. Even if these areas are often characterized as low- or semi-skilled work, the mobilization of employees' informal experiential knowledge plays an important role in lean production systems. Due to increasing quality requirements, which are combined with shorter time spans and increasingly complex process chains, logistics and assembly are under increasing pressure to prevent errors in order-picking and component assembly.

Assistance systems are now expected to help get this problem under control. A central area of application is internal logistics operations in industrial enterprises. So-called pick-by-light and pick-by-voice assistance systems have been used in this field for some time. They show picking staff the articles to be selected via light signals or computer-generated voices. Examples of technologies that further develop such approaches are pick-by-vision systems supported by data glasses. In addition to identifying picking errors, the main goal of introducing these pick-by-vision techniques according to the engineering literature is to reduce picking times (Günthner et al. 2009; Baumann 2013).

The data glasses are connected (mostly via WiFi) to the order management system. This provides information about what products are needed, where they are in the warehouse, and in what order they have to be picked. All details and instructions are displayed step by step on the data glasses. The camera built into the data glasses or the RFID chips[2] worn on the body confirm that the correct products have been picked. It is also (at least theoretically) possible to pinpoint the exact location of employees. Reports on the use of data glasses at Tesco and Amazon show that employees' productivity data, movements, and interactions are recorded, evaluated, and used to monitor performance (Wilson 2013; Rawlinson 2013; Moore/Robinson 2016; Nachtwey/Staab 2016), although comparative surveillance techniques do not appear to be common in the automotive industry to date.

Another example of the use of assistance systems in assembly of industrial products can be found in a pilot project conducted on a multiproduct assembly line at an automotive supplier. The U-shaped line comprises nine workstations. At the first one, the workpiece is inserted into a workpiece carrier equipped with an RFID chip, thus ensuring reliable position data. Gripping of the parts is controlled by light signals. If the incorrect part is gripped, the subsequent processes are also blocked at the next workstations. Employees

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[2] Radio Frequency Identification (RFID) is a central technological element that facilitates the coordination of logistics. RFID enables the contactless and unique identification of objects and is thus a fundamental element of the industrial application of the internet of things.

log on to the workstation via a bluetooth device, which stores information about their height, physical characteristics, and their specific previous knowledge. This information is used to adapt the workstations to the employees' individual requirements. Employees' hand movements are followed by cameras, which display whether these have been carried out correctly on a projection screen. The target times for the individual activities are supplied by the industrial engineering department. The system aims to ensure that the activities are carried out in accordance with predefined standards down to the smallest detail (e.g., how built-in parts are gripped and installed).

Of course, these few examples do not offer a sufficient basis from which to generalize. However, it becomes clear that the introduction of assistance systems does not necessarily increase autonomy, personal responsibility, and self-development as claimed by the statement quoted in the introduction of this chapter. Instead, inscribed in the assistance systems, there is a logic that aims to generate adherence to preplanned, optimized courses of action by instructing workers on the correct hand grips and preventing the wrong ones.

Of course, assistance systems can also be designed to adapt flexibly to the level of knowledge and support required by employees, for example, when information is transmitted according to their level of experience. Whether they are used in this way depends, however, on the orientation of human resources policies in the respective company (cf. Kuhlmann et al. 2018). Even in a positive scenario, in which assistance systems adapt flexibly to the needs of employees and focus on the provision of process-related information, their impact on learning might by problematic. Our empirical data from use cases shows that learning effects in work settings where digital assistance systems were used for training might be weaker than expected because employees just let themselves be guided by the technology without actively processing the individual work steps—a phenomenon that is comparable to the "satnav effect" in individual navigation.[3] In addition, the use of assistance systems raises the question of how the application of such technologies shapes the content of experiences and ideas employees can contribute to improvement processes. It seems likely that employees will then focus on the functioning of the assistance systems themselves, thus directing problem-solving activities towards secondary problems and detours rather than towards the production processes as such.

Although the current motivation for the use of assistance systems is to ensure a greater standardization and control of work, employee acceptance is relatively high in most of the cases studied by us. There may be problems regarding poor wearing comfort (e.g., glasses that are too heavy), limited field of vision, limited battery life, etc., yet employees

3 This refers to the effect that occurs when using satnav devices in road traffic. Such devices guide users relatively reliably to their chosen destination and thus technically enhance their navigation skills. However, blind trust in the technology can lead to a loss of independent navigation ability if individuals blindly follow satnav directions without making individual efforts to orient themselves or contextualize the information.

rarely criticize the external control by the technical systems themselves. An important reason is that the systems also offer advantages such as reductions in workplace stress arising due to growing pressures to avoid errors in an increasingly complex work environment. These stressors seem to us under-researched in the field of sociology of work. Increasing individual autonomy in a highly interdependent and standardized work process might not be a feasible strategy for improving work quality. A more promising approach might focus on enriching work in the sense of including more problem-solving and optimization activities (which also provide learning opportunities) and providing more time autonomy i.e., more freedoms to switch between production work and other activities.

3.2 Data-based process management and scope of action for skilled work

A major element of *Industrie 4.0* is the integration of different layers of the company-internal information systems (see Gronau 2014, p. 7), from machine control systems and manufacturing execution systems (MES) to enterprise resource planning (ERP) systems, which is intended to create comprehensive process transparency. Nyhuis et al. (2017; see also Schlick et al. 2014; Meyer et al. 2018) show in their work on the transformation of production planning that new optimization potential may arise, for example, in (a) production program planning, through the use of big data analyses to forecast future demand, (b) order management, through real-time information on the status of order processing and (c) production control, due to more and more precise data on machine utilization, order status, and faults.

This will also have an impact on areas of work that have traditionally required high skills and work experience. It is reasonable to expect that the new data-based process optimization techniques will lead to a decrease in repair and maintenance activities that are currently undertaken by highly qualified and experienced groups of employees whose work is hard to standardize as it affords instant reactions to very specific problems that so far could barely be predicted in advance.

This also applies to the work of automated equipment operators. Here, in a case we examined, the introduction of a new order management and production control concept used by an automotive electronics supplier went hand in hand with changes of the work organization. Prior to the changes, each production line in the factory was operated by a highly skilled equipment operator who was responsible for monitoring, maintenance, and also material supply for his or her line. Under the new system, specialized teams now take care of monitoring/problem solving, maintenance and material supply. Every worker is equipped with a tablet computer and the order management and production control system informs the teams (ideally: in real time) if a problem occurs in the production process or in the supply chain. The system should automatically recognize which employees are available and qualified for the task. While each team is responsible for a specific task (e.g., process monitoring or maintenance), all workers in a team should be able to take care of each of the production lines. The aim is to achieve greater flexibility and better utilization of working hours of equipment operators. The impact on skill requirements is ambiguous. We can observe a polarization of skill requirements between the teams, because material supply tasks can now, for example, also be allocated to semiskilled workers, while in the area of problem solving and maintenance at least some of the skilled workers must be familiar with multiple pieces of equipment, which goes hand in hand with increasing skills requirements.

Far-reaching changes are already visible in the area of maintenance as well. Self-diagnostic systems in machines and plants are already highly developed. With *Industrie 4.0* concepts, so-called IoT gateways (internet-of-things interfaces) are gaining in importance, i.e., software systems that bring together and display sensor data from plants in real time. In this way, immediate action can be taken or preventive measures can be planned. Within comprehensive process management and support systems, data from many production lines are combined and can serve as a base for new process optimization strategies (e.g., through data mining).

The "smart maintenance" approaches discussed in the context of *Industrie 4.0* take this development one step further (Acatech 2015; Günther et al. 2015). Günther et al. (2015, p. 20) emphasize that the maintenance profession is moving away from the image of the "machine whisperer" and towards a focus on data analytics. The concept of "smart maintenance" formulated by Acatech emphasizes the possibility of centralizing equipment monitoring and problem-solving processes resulting from the new quality of data availability and the opportunities offered by real-time data analysis. In such maintenance centers, university-trained engineers could work together with data analysts. Maintenance personnel themselves follow the instructions from the maintenance center and would therefore require less experience and technical knowledge:

> "From this maintenance center, the operational workers who have completed a basic qualification as generalists or generalists in maintenance would be individually guided in their work. In conjunction with the use of suitable assistance systems, this approach compensates for workers' lack of experience or qualifications and enables them to be deployed throughout the field." (Acatech 2015, p. 24)

Although these approaches are still in their infancy, there are signs that such a standardization of activities is underway. Replacing mechanical safety systems in the elevator industry with electronic solutions means, for example, that elevator monitoring and planning can be handled by central monitoring centers. Malfunctions are largely avoided by predictive maintenance. Today's elevator mechanics are increasingly acting as "parts exchangers".

The current rationalization of maintenance and automated equipment operators' work is following a path which has been developed by lean production concepts. Systematic process monitoring and statistical process control concepts were among the core ideas that were taken up by Japanese companies and further developed into so-called total productive maintenance (TPM). In line with this, predictive maintenance systems have been established in many companies since the 1990s in which forecasts on possible failures are made based on data on material loads and wear durations. This allows maintenance work to be planned in such a way that affected parts and components are replaced before the system fails (Wireman 1991), even though the existing systems and data are still far from perfection. The need to get rid of fixed equipment control stations and to flexibly use equipment operators have also already been highlighted in earlier papers as an important element of Toyota's approaches to automation (Sugimori et al. 1977, p. 558).

However, there is an important difference between the TPM concepts and "smart maintenance". The TPM literature emphasizes the need for crossfunctional and crosshierarchical improvement processes, in which the shop floor teams should also be included (Shirose 1996; Japan Institute of Plant Maintenance 1996). Under the heading "autonomous maintenance," the shop floor teams take on tasks such as equipment monitoring, registration of faults and problems, problem analysis, and simple maintenance activities. To ensure that these tasks are completed, the team activity boards list the daily TPM duties (Japan Institute of Plant Maintenance 1996). The team activities are part of the comprehensive optimization activities, which also include the maintenance department and supervisors and managers from several hierarchy levels.

While the tradition of lean production emphasizes the combination of data-based analysis with competence development and shop floor experience, such an emphasis is absent in the discussion about *Industrie 4.0* applications. The concept of "smart maintenance" rather suggests making such investments in shop floor knowledge superfluous through technology.

However, it is doubtful whether this technology-fixated approach will work. At the very least, experience with previous automation processes suggests that the elimination of experience and learning opportunities through data-based process control, monitoring, and optimization can lead to a lack of human problem-solving competences in the event of unexpected system failures (Bainbridge 1983; Weyer 1997 and 2007). For this reason, too, works councils and researchers should underscore the importance of experiential knowledge on the shop floor against concept-heavy IT expertise and defend the importance of skilled workers when testing and adapting *Industrie 4.0* solutions to meet changing circumstances and requirements.

3.3 New approaches to the design of assembly line work

Companies from different industries are working on approaches to modularized production using cyber-physical systems in assembly and logistics.[4] It is emphasized that such approaches would grant leeway for a more innovative work design, since they supposedly represent a departure from the corset of tight coupling of processes in assembly line work. The scope and limits of these approaches can be illustrated by an experimental concept developed by Audi (Audi 2018). According to this concept—which is so far implemented in a laboratory only—the vehicles are to be placed on autonomous transport systems and provided with information on the possible sequence of the assembly steps. On the basis of this information, the vehicles themselves then decide which assembly station they will go to next, taking into account the capacity utilization of the station, the "traffic situation," and other relevant factors. This will potentially create a self-regulating system.

Efficiency gains are expected from the fact that each vehicle seeks its optimum path through production, which means unnecessary steps can be skipped, for example, when a part is not needed for a particular model. The assembly stations can thus be optimally utilized. Disruptions at individual stations due to malfunctions also do not necessarily have to affect the entire production flow.[5]

One of the goals of the project, according to Audi, is to increase the autonomy of employees in assembly. The intention is that each of the future assembly stations will be responsible for a complete work step (for example, the assembly of the cockpit). To enable this, uniform cycle times will be abandoned. The duration of the work steps will instead depend on the quantity and content of the tasks and range between one and four minutes. Compared to the highly rationalized assembly line work following a uniform cycle time, this should offer the possibility of increasing the quality of work. At the same time, the intention is to create scope for managing stressors and for improving the

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[4] Cyber-physical systems are networks of machines, storage systems, and equipment in which the components "exchange information independently, trigger actions, and control each other independently" (Acatech/Forschungsunion 2013, p. 5). Together with a number of partners such as the Fraunhofer Society, the University of Stuttgart, and other organizers, Daimler operates the Arena2036 research factory, in which new modular assembly concepts based on cyber-physical systems are being tested (Steegmüller/Zürn 2017; Daimler 2018). Audi has already switched over to transporting vehicles between individual assembly stations at the R8 assembly plant in Neckersulm using driverless transport systems, which means that the assembly layout can now be changed much more flexibly, but otherwise the assembly at the R8 still seems to follow traditional flow and pull concepts (Plattform Industrie 4.0 2018).

[5] At the same time, however, the complexity of the assembly system and the difficulties in synchronizing the material flows increase. To give just one example: If the assembly stations can be started up again and again in a new sequence, how are the logistics processes organized and the JIT parts supply ensured? The superiority of the experiments in modular production must therefore still be demonstrated in practice.

working conditions for older or disabled employees. The flexibility of the system should also reduce stress potential, for example, if employees are missing and work at individual stations thus takes longer or if an error has to be rectified. The desired flexibility of the cycle time of the individual assembly stations to up to four minutes goes only slightly beyond the scope offered by today's assembly lines, but potentially even greater deviations from the principle of uniform cycle time could be feasible. Such concepts recall Swedish approaches to the reorganization of work in the 1980s and 1990s (Sandberg 1995).

To sum up, the new assembly approaches could theoretically lead to an expansion of the work content and an enrichment of the work tasks at the stations with indirect activities related to team organization, problem solving and other tasks. Nevertheless, since this model is also subject to high profitability pressures, it is at least unclear to what extent the promises of autonomy offered by this sociotechnical path can actually be realized. It is true that in the case of modular production described here, the rigidity of the processes on the assembly line is loosened up, but it is misleading to interpret this as a departure from flow production. The reorganization of the assembly line could even open up scope for an intensification of work. After all, the processes can now be timed much more flexibly or the activities at the individual stations can be bundled in such a way that the “idle times,” in which employees wait for the next task, are reduced and work is thus condensed.

4. Conclusions

The discussion of initial application examples of *Industrie 4.0* technologies casts doubt on the assertion that these developments will be accompanied by greater employee autonomy. Although the empirical findings to date do not allow us to paint a precise picture, let alone come to a final judgment, the impression is that the use of digital technology intensifies the tendencies towards standardization and control of work in lean production. The possibilities of the new digital assistance systems go beyond traditional lean production techniques, in that they enable real-time control of work processes and individualized guidance for employees.

How can we assess this finding? Although the presented cases by and large represent problematic tendencies, we believe that “autonomy” is not the only indicator for the evaluation of working conditions in emergent production systems. Looking back at the debates about lean production, Adler (2007) criticized the prevailing understanding of autonomy in the sociology of work as backward-looking, because it is based on the model of an isolated craftsman, which is no longer compatible with the conditions of modern production. Using Marx's argument about the dialectic between productive forces and relations of production, Adler emphasized that an increasing use of technology inevitably strengthens interdependence at various levels in the long term.

Higher quality depends on more closely linked value chains and industrial structures. More complex technologies also require a stronger integration of different functions, such as development, planning, production, etc. All this reinforces interdependence in the work process.

The decisive question is not, therefore, whether the organization of work enables individual autonomy—for this is illusory under the conditions of modern production (cf. also Adler/Cole 1993)—but whether the rules of interdependence and cooperation are defined in a participatory and cooperative process instead of top-down. The reference point for emancipatory demands on work should be a participation-oriented interdependence (Adler speaks of "collaborative interdependence") rather than individual autonomy.

To what extent does the use of *Industrie 4.0* technologies make it possible to strengthen collaborative interdependence? In lean production concepts, the team-based involvement of the shop floor employees in improvement and problem-solving processes has always been emphasized. This aspect, however, does not play a role in the *Industrie 4.0* discussion, which is instead dominated by approaches suggesting that the increasing importance of data-based process control will reduce the relevance of experiential knowledge and push the competences of shop floor employees into the background. An important challenge for the organization of work is therefore to design new forms of employee participation, especially as the approaches taken so far have been inadequate. Although employees in the automotive companies we studied are informed and consulted on the introduction of digital assistance systems, these are typically one-off events that are mostly limited to questions of ergonomics and handling (cf. Evers et al. 2018). So far there are no studies on how the use of digital assistance systems affects teamwork and problem-solving activities on the shop floor. The first studies in the logistics sector conclude that, especially with regard to simple tasks, digitalization leads to a reduction of the "need for independent problem solving" on the shop floor (Mättig et al. 2018, p. 70).

There might be some potential for improving working conditions through *Industrie 4.0* concepts if we focus on issues related to the autonomy to determine working times and working schedules according to the employees' needs. We can observe an increased demand for flexible and shorter working hours, as well as for the scope to shift between part-time and full-time work, leave periods for child-rearing, and time spent taking care of relatives. For the shop floor, making these wishes a reality means more frequently shifting employees from workstation to workstation and thus greater coordination and skills problems. Digital systems to guide work processes and assign tasks can help manage these challenges and reconcile employee-oriented working time policies with productivity requirements. The new technologies can also have positive effects in terms of supporting greater task rotation and integrating new groups with little industrial experience into production. *Industrie 4.0* technologies are being used in a context of demographic changes, which are reflected in growing recruitment problems and high employee turnover rates. In many companies in manufacturing industries, a generational rupture is imminent, and the younger employees might be less willing to accept rigid working time schedules and task allocations.

The extent to which the opportunities offered by *Industrie 4.0* can be used to influence working time and work organization does not, however, depend on technology, but on the outcome of bargaining and disputes around such issues. The technology-fixated discussion about *Industrie 4.0* can be used as a chance to address the conditions of employment at a time of demographic change comprehensively—and thus to make corresponding demands related to working conditions and work schedules.

It is important, however, to acknowledge the possible impact of the digital process control and assistance systems on power relations in the workplace. As these technologies might reduce the importance of the employees' experiential knowledge and make their inputs more exchangeable, they could undermine the bargaining power of the workers. Under these circumstances, institutionalized resources of labor power, such as co-determination in Germany, as well as associational power through organizing efforts might become all the more important.

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